United States Department of Agriculture
Soil Conservation Service
Washington, D. C.

PRELIMINARY REPORT ON WATERSHED STUDIES NEAR WACO AND GARLAND, TEXAS

Rates and amounts of runoff and related information for the hydrologic design of conservation practices and structures in the Blacklands of Texas.

By

L. L. Harrold, D. B. Krimgold, and L. A. Westby

Division of Water Conservation and Drainage
Soil Conservation Service - Research

Prepared for use by technicians of the Soil Conservation Service.
Not for general distribution

SCS - TP - 53

APRIL 1944

FOREWORD

This report for the Blacklands of Texas is the first of a series of preliminary reports containing recommendations and suggested methods for the hydrologic design of conservation structures and practices in important agricultural areas represented by watershed studies of the Soil Conservation Service.

Recommendations contained herein must be considered tentative and subject to revision in the light of additional records and of further developments in the field of Agricultural Hydrology. Definite quantitative relationships between rates and amounts of runoff from small agricultural watersheds and the factors affecting them have not yet been established and proved. This, and the fact that frequencies of occurrence must always be considered in the economic design of conservation practices, requires much longer periods of record than are now available for adequate analyses.

M L Nichols

M. L. Nichols
Chief of Research

ACKNOWLEDGMENTS

The establishment of the studies and the collection of the records utilized in this report involved the work of the authors and of many other members of the former Hydrologic Division of the Soil Conservation Service, C. E. Ramser, Chief. Arthur J. Stewart, Jr., of the Blackland Experiment Station staff, assisted in the analysis of the data. The construction of the measuring devices, surveys of the watersheds, and field observations of the Garland studies were carried out by Operations personnel assigned by Region 4. Information on silting of reservoirs was furnished by Carl B. Brown, Head, Sedimentation Section, Research. Mr. Howard Matson, Chief, Regional Engineering Division, Fort Worth, Texas, reviewed this report and offered valuable practical suggestions which have enabled the authors to present the information in a form most suitable for direct application in the action program of the Soil Conservation Service.

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SYNOPSIS

In this publication are given preliminary results from the Blacklands Experimental Watershed near Waco, Texas and the runoff studies near Garland, Texas, conducted by the Soil Conservation Service in cooperation with the Texas State Agricultural Experiment Station.

Tentative values of rates of runoff with recurrence intervals of 2, 5, 10, and 25 years, for use in the design of conservation structures in the Blacklands of Texas, are given in tables 2 and 3 (pp.5 & 8) and figure 3.

For clean cultivated and mixed cropland in the northern and southern sections of the Blacklands, the relation between drainage area and depths and surface areas of farm ponds which can be expected to be filled within a reasonable time of completion and depended upon to furnish 0.2 and 0.5 acre-foot of usable water per year is shown in figures 6 and 7. The use of the graphs in determining the minimum size of drainage area required to furnish a desired supply in ponds of given depths and surface areas and in determining the proper dimensions of ponds for a given drainage area is illustrated in problem A (p. 18). Graphs showing dependable amounts of runoff and rainfall during critical periods for the two sections of the Blackland prairies are given in figures 4 and 5, respectively. Amounts of rainfall and runoff which can be expected 75 percent of the time are given in table 4. The use of this information and of evaporation data in table 5 in determining minimum drainage areas for required amounts of usable water other than 0.2 and 0.5 acre-foot per year, and the procedure to be followed in the hydrologic design of farm ponds with dimensions not covered in figures 6 and 7, are illustrated in problem B (p. 20).

The curves and procedure for the design of farm ponds, mentioned in the preceding paragraph, apply to excavated ponds with steep side slopes and water-surface areas large enough so that the percentage differences between the water-surface areas when the pond is full, half full, and nearly empty are reasonably small. No factors of safety need be applied to the results obtained with these curves and procedure as they are based on the assumption of concurrent minimum rainfall, minimum runoff, and maximum evaporation.

It must be understood that some time (12 to 20 months) may elapse before newly constructed ponds are filled and begin to function in accordance with the assumptions underlying the procedure outlined in this report.

To avoid misunderstanding and possible disappointment the meaning of the recurrence interval, as explained on page eighteen of the text, must be carefully pointed out when technical assistance is rendered in planning farm ponds.

Farm ponds designed by the method outlined in this publication will hold sufficient water for production of fish. The use of minimum drainage areas determined by this method will result in the least waste of water over the spillways.

Surface runoff from land in permanent meadow is too infrequent to be considered as a dependable source of water supply. No information is available on total runoff from pasture land. The information and suggested methods for the design of farm ponds apply therefore only to mixed crop and cultivated land. No provisions are made for eroded material reaching the pond, as it is assumed that unterraced drainage areas with slopes in excess of 3 percent will be avoided and that meadow strips sufficient to prevent serious silting should and will be provided at every properly designed pond. Values of average annual amounts of eroded material and of estimated annual amounts of deposition in farm ponds are, however, given in tables 6 and 7 (p. 13).

Seepage losses are not considered. It is assumed that for excavated ponds in the Blacklands such losses will be negligible if care is taken to avoid sites underlain by shattered marl or chalk and if large portions of the ponds are not exposed to drying over long periods.

Spillways for farm ponds shall be designed in accordance with the standard Soil Conservation Service engineering procedure for the Blacklands. If the spillways are designed to carry the maximum rate of flow from the drainage area for a recurrence interval of 10 years, as shown in tables 2 and 3 (pp.5 & 8), with the recommended freeboard, a 25- or 50-year peak flow probably will not cause serious damage to the structure.

INTRODUCTION

Adequate information on rates and amounts of runoff from small agricultural areas is indispensable in the planning of soil and water conservation practices and structures. When the Nation-wide program of soil conservation was inaugurated a decade ago, very little if any information was available on runoff characteristics of small agricultural watersheds and on the effect of conservation practices in the several agricultural regions of the country.

With the expansion of the soil and water conservation program the need for such information became acute. To meet this need, a number of research projects were established in some of the most important agricultural areas of continental United States.

The Blacklands Experimental Watershed near Waco, Texas, and the runoff studies near Garland, Texas, were established in 1937 and 1938, respectively, for the purpose of securing such information for the Blackland prairies of Texas, one of the most important agricultural areas in the country (fig. 1). The studies were conducted in cooperation with the Texas State Agricultural Experiment Station.

The work on the experimental watershed near Waco included (a) measurements of precipitation, runoff, and suspended silt load on 18 natural watersheds ranging in size from 20 to 5900 acres, cropped and tilled in accordance with prevailing practices; and (b) more detailed studies of precipitation, runoff, and erosion (including measurement of total eroded material) on twelve 3-acre watersheds with a planned program of cropping and tillage. The plans for the studies called for a preliminary calibration period at the end of which recommended conservation practices were to be followed on some of the watersheds while the others were to be continued in prevailing practices, thus affording a means of determining the effects of conservation practices on runoff and erosion. Lack of funds and personnel made it necessary in July 1943 to discontinue the collection of records on all except three of the large watersheds near Waco before the comparative phase of the studies began.

In addition to precipitation, runoff, and erosion data, the work on the Blacklands Experimental Watershed included studies of soil moisture and volume-weight, and observations of evaporation, soil and air temperatures, wind movement, and relative humidity.

The runoff studies near Garland, which served to supplement the more intensive investigations on the Blacklands Experimental Watershed, were limited to measurements of precipitation and runoff on six small watersheds, and records of air temperature and of relative humidity. The six watersheds included a 97-acre terraced area, a 25-acre stripcropped area, a 10.4-acre area in native meadow, and three clean cultivated areas of 16.2, 14.5, and 13.6 acres. The Garland studies have not been curtailed, and records are being obtained on all except the terraced area which was discontinued in June 1942 due to failure of the land owner to maintain the terraces.

The compilation of runoff and related data is a time-consuming process. With the limited facilities available only part of the records thus far collected have been compiled. However, sufficient information is now available on which to base preliminary conclusions, suggestions, and recommendations which of necessity must be considered tentative and subject to revision in the light of additional records and of further analysis of the records thus far obtained. It should be pointed out that even a complete 5-year record of runoff and related data cannot be considered adequate for analyses on which definite conclusions and recommendations can be based.

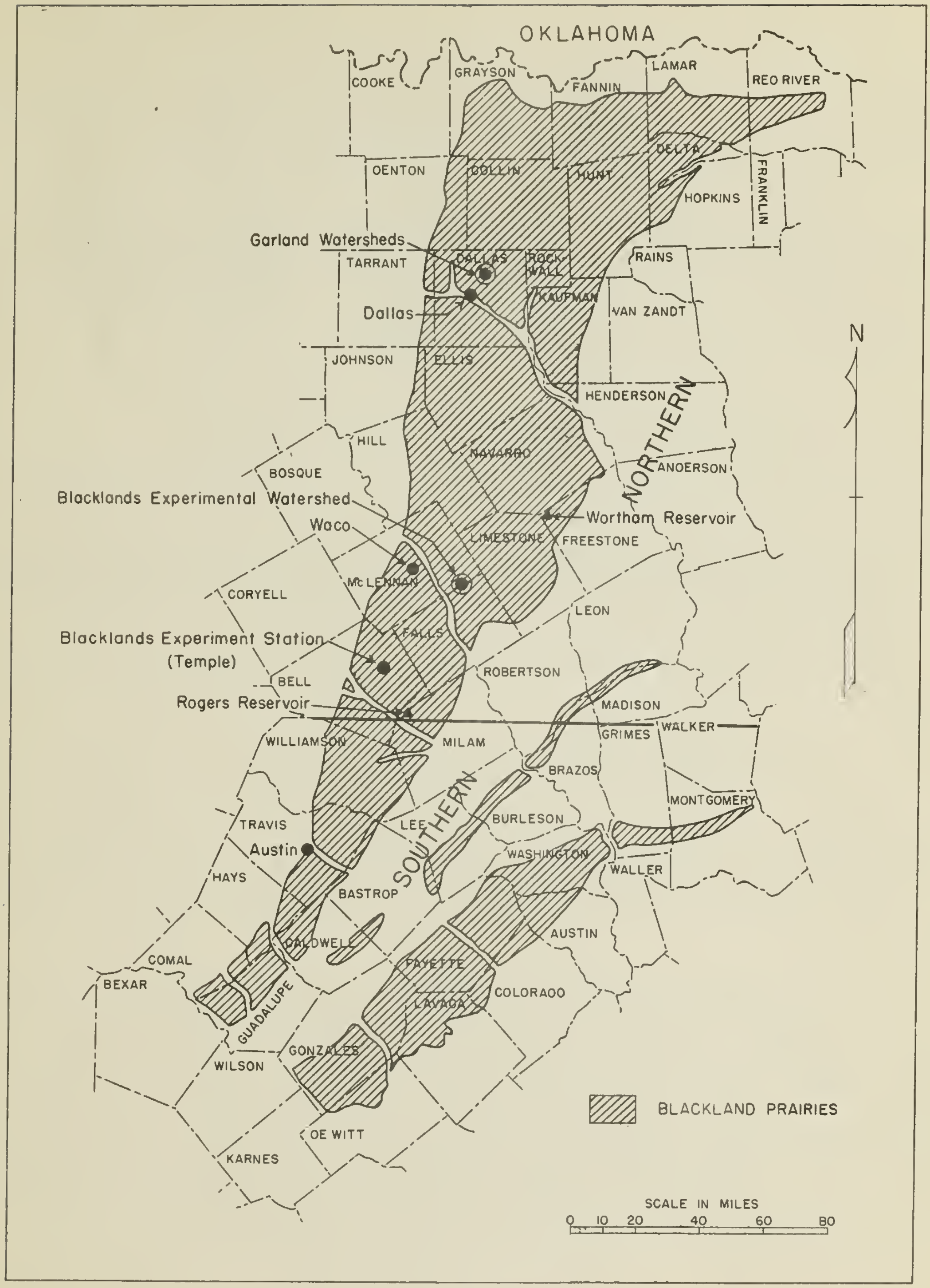

Figure 1.– Blackland prairies of Texas.

The discussion of results and tentative suggestions which follow are based on: Records from the Waco and Garland watersheds; a 50-year U. S. Weather Bureau record of rainfall at Dallas, Waco, and Austin; evaporation data at Waco, Austin, and Temple; sedimentation survey data for two reservoirs in the Blacklands; and results of sedimentation studies conducted in various parts of the country by the Soil Conservation Service.

A complete description of the experimental watershed near Waco will be found in U.S.D.A. Hydrologic Bulletin No. 5, "The Agriculture, Soil, Geology, and Topography of the Blacklands Experimental Watershed, Waco, Texas." Data for 1937-1939 were published in Hydrologic Bulletin No. 2, "Hydrologic Data, Blacklands Experimental Watershed, Waco, Texas." A description of the Garland studies, including maps and photographic views of the watersheds and of their instrumentation, are contained in an unpublished manuscript entitled "Description of Runoff Studies near Garland, Texas."

DISCUSSION OF RESULTS AND TENTATIVE SUGGESTIONS

In the Blackland prairies of Texas, conservation structures and practices, the planning of which must be based on adequate runoff data, fall in two general classes, namely:

A. Structures such as terraces, terrace outlet channels, check dams, spillways, grassed waterways, diversion and drainage ditches, and other structures used in the disposal of excess rainfall which cannot be retained advantageously in the soil.

B. Small farm ponds used to provide drinking water for livestock and for other purposes.

A. Peak rates of runoff for the design of conservation structures

The highest rates of runoff recorded during the period of 1938-42 at Waco and during 1938-43 at Garland are shown in figure 2. The highest rate on the 97-acre terraced area at Garland, not shown on the graph, was only 0.71 cubic feet per second per acre. However, the maximum rates of rainfall experienced on this watershed prior to the discontinuance of the record in June 1942 were lower than those recorded on the other Garland and Waco watersheds.

The brevity of the records makes it inadvisable to draw definite conclusions. It may be well, however, to discuss briefly the information shown in figure 2, and to indicate how it can be used as a general guide until additional records and further analysis make it possible to draw more definite conclusions. The shape of the envelope curve in figure 2 is determined primarily by the rates of runoff recorded on the Waco watersheds on June 10, 1941, and on the five unterraced Garland watersheds on April 20, 1942. On October 31, 1940, when rainfall intensities on the Waco watershed were somewhat higher than on June 10, 1941, rates of runoff from all watersheds over 30 acres in size were only about one-third as high as those produced by the June 10, 1941 storm. The maximum rainfall intensities recorded on both dates, and values of 5, 10, and 25-year recurrence intervals for several durations given in U.S.D.A. Misc. Pub. 204 by David L. Yarnell, are shown in table 1.

Table 1.-- Maximum rainfall intensities for storm of October 31, 1940 and June 10, 1941 on the Waco watersheds compared with values given in U.S.D.A. Misc. Pub. 204

Time interval	Rainfall intensity				
	October 31, 1940	June 10, 1941	U.S.D.A. Misc. Pub. 204		
			5-year	10-year	25-year
Minutes	Inches per hour	Inches per hour	Inches per hour	Inches per hour	Inches per hour
5	7.44	7.20	6.9	7.7	9.4
10	7.32	6.24	5.8	6.4	7.5
15	6.48	5.60	5.3	5.8	7.0
20	5.40	4.98	4.5	5.2	6.1
30	3.96	4.04	3.8	4.5	5.2

The higher rates of runoff on June 10, 1941 resulted from intense rainfall occurring when soil moisture and tillage conditions were conducive to higher rates of runoff than on October 21, 1940. Although the rainfall intensities indicate a recurrence interval of 10 years for the June 10 storm, it is quite probable that the recurrence interval of the coincidence of high rainfall intensities and of watershed conditions conducive to such high rates of runoff would be greater. It is therefore suggested that until additional data are available and further analyses are made the values shown by the envelope curve (fig.2) be considered of a 25-year recurrence interval. With this assumption, and the further assumption that maximum rates of runoff for other recurrence intervals will vary directly with maximum rainfall intensities as given by Yarnell (U.S.D.A. Misc. Pub. 204), the tentative values given in table 2 and shown on figure 3 were developed and are suggested for use in the design of conservation structures on unterraced land in the Blacklands.

The records from the Garland 10.4-acre meadow watershed indicate that while total runoff from pasture and meadow watersheds is much lower than from cultivated or mixed-cover watersheds, rates of runoff from meadow and pasture watersheds may be rather high. However, the occurrence of high rates of runoff from meadow watersheds will be much less frequent than those from cultivated fields. The values given in table 2 for meadow and pasture are 70 percent of those for cultivated land.

Table 2.-- Rates of runoff in cubic feet per second per acre from unterraced areas for various recurrence intervals.

Size of drainage area	Recurrence interval of							
	25 years		10 years		5 years		2 years	
Acres	Cultivated [1]	Meadow or pasture	Cultivated [1]	Meadow or pasture	Cultivated [1]	Meadow or pasture	Cultivated [1]	Meadow or pasture
5 or less	6.5	4.5	5.5	3.9	4.7	3.3	3.8	2.6
10	4.8	3.4	4.2	3.0	3.5	2.5	2.8	2.0
20	4.4	3.1	3.8	2.7	3.2	2.3	2.6	1.8
40	4.0	2.8	3.5	2.4	3.0	2.1	2.3	1.7
100	3.8	2.7	3.3	2.3	2.8	2.0	2.2	1.6
300	3.6	2.5	3.0	2.2	2.6	1.7	2.0	1.4

[1] Clean cultivated including up to 40 percent in meadow, pasture, and close growing crops.

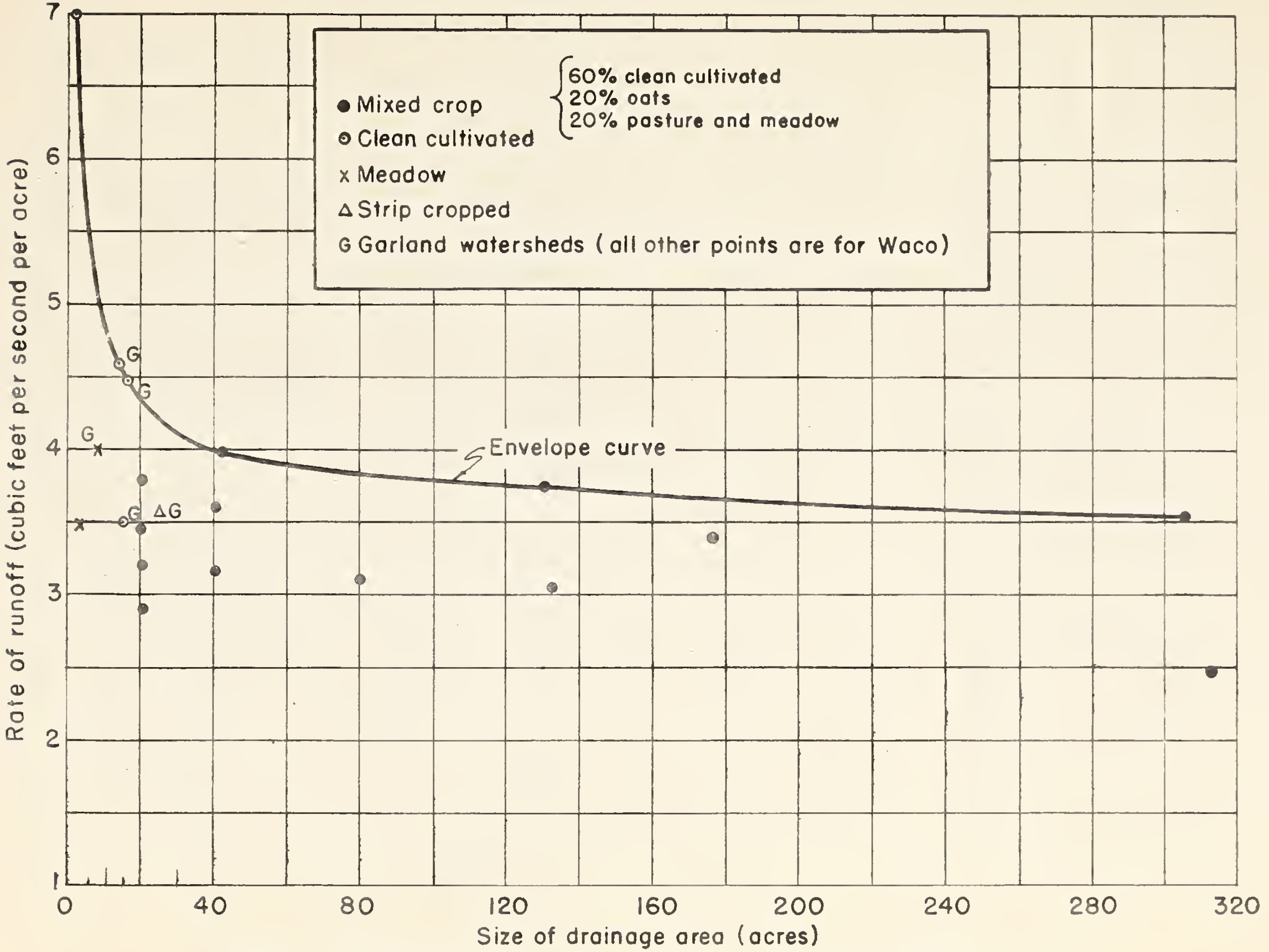

Figure 2—Maximum rates of runoff recorded on Waco watersheds 1938-42 and Garland watersheds 1938-43

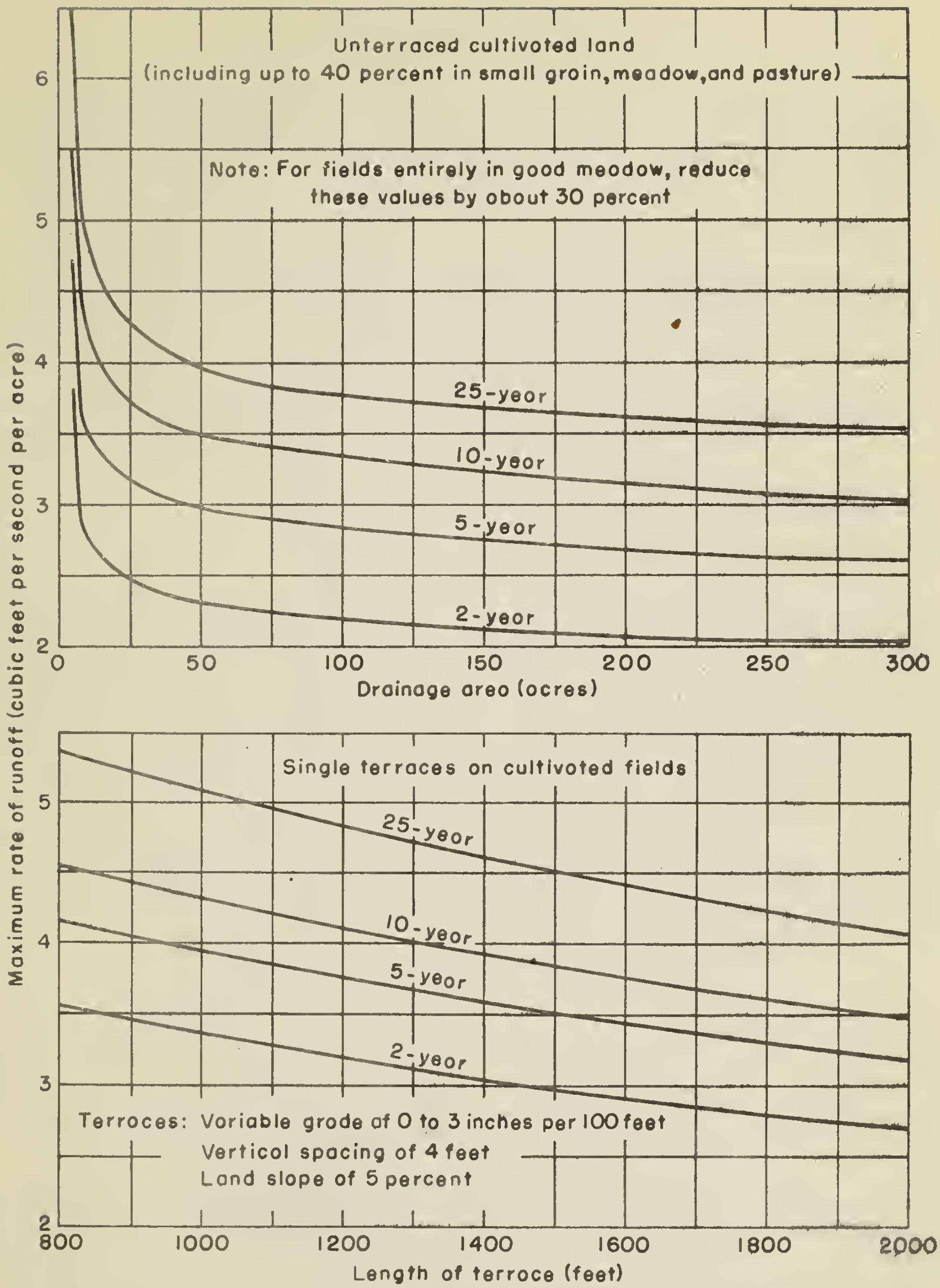

Figure 3—Rates of runoff from terraced and unterraced land for various recurrence intervals

Rainfall and runoff records on terraces at the Blacklands Experiment Station at Temple were used to derive tentative design values of rates of runoff for single terraces of various lengths given in table 3 and shown on figure 3. These values apply to variable grade (0 to 3 inches per 100 feet) terraces spaced at 4-foot vertical intervals on 5 percent land slope.

Table 3.-- Rates of runoff in cubic feet per second per acre for single terraces on cultivated land for various recurrence intervals. Terraces: Grade 0 to 3 inches per 100 feet variable, vertical spacing 4 feet, land slope 5 percent

Terrace length	Rates of runoff for recurrence interval of -			
	25 years	10 years	5 years	2 years
feet				
800	5.4	4.6	4.1	3.6
1000	5.1	4.3	3.9	3.4
1200	4.8	4.1	3.7	3.2
1400	4.6	3.9	3.6	3.0
1600	4.4	3.7	3.4	2.9
1800	4.2	3.6	3.3	2.8
2000	4.1	3.5	3.2	2.7

The rates of runoff given in table 3 can be used in the design of terrace outlet channels serving a small number of terraces with closely spaced outlets. When the lengths of the several terraces in the system served by the outlet channel do not differ much or when the greater part of the area is drained by the longer terraces the rate of runoff for the longest terrace in the system is used to arrive at the design rate for the outlet channel. For example, the 10-year rate of runoff per unit of area for a 10-acre area having five terraces of 800, 900, 1700, 1750 and 1800 feet length would be that for a terrace 1800 feet long -- 3.6 second-feet per acre or 36 cubic feet per second for the entire area.

When the greater part of the area is drained by the shorter terraces the rate of runoff in the terrace outlet channel will be greater than that corresponding to the longest terrace in the system. In such cases the design rate should be selected by the designer with the particular terrace system in mind.

B. Hydrologic data for the design of farm ponds

To serve the purpose for which they are intended, farm ponds must be so located and designed as to insure an adequate supply of water. A stock pond which is dry, or provides insufficient water every year or every other year, is of little or no value unless other sources of water supply are available. On the other hand, a pond which on the average can be depended upon to provide sufficient water 24 out of 25 years can be considered an adequate water supply.

The dependable supply of required amounts of water and the amounts which will be wasted over the spillway in a pond with a given depth and surface area are determined by the following hydrologic factors:

(a) Amounts of runoff from the watershed draining into the pond which can be expected to be equalled or exceeded at various recurrence intervals

(b) Amounts of rainfall (irrespective of whether or not they produce runoff) falling on the pond which can be expected to be equalled or exceeded at various recurrence intervals

(c) Amount of water which will be lost by evaporation and seepage

(d) The rate of silting which determines the useful life of the pond.

The data thus far obtained are insufficient for a complete analysis on which definite recommendations can be based. It is, however, deemed advisable to present tentative conclusions and suggestions which can be followed until such time as more nearly adequate data and methods of analysis become available.

Amounts of rainfall and runoff

Rain falling on the surface of the pond and surface runoff from the drainage area are the only sources of impounded water except where springs or seeps contribute. The records from the Waco and Garland watersheds, ranging in size from 10 to 300 acres, and a 50-year record of rainfall at Dallas, Waco, and Austin, indicate the following:

1. Surface runoff from small watersheds entirely in meadow is too small and too infrequent to be considered in the design of small, relatively shallow ponds.

2. No information on runoff from pasture land is available.

3. Within the range of slopes commonly encountered on unterraced land in the Blacklands (0 to 3 percent), the records show no effect of land slopes on total surface runoff.

4. Total surface runoff from cultivated land with graded terraces in the Blacklands is about the same as from unterraced cultivated land.

5. The distribution of rainfall at Dallas, Waco, and Austin is sufficiently different to require a division of the Blacklands into northern and southern sections.

6. Amounts of rainfall and runoff for a period of 20 months which can be expected 3 out of 4 years (table 4), average evaporation (table 5), and required amounts of usable water for the same period, must be considered in determining minimum drainage areas required to fill a farm pond within a reasonable time after completion.

Table 4.-- Amounts of rainfall and runoff for 20 months which can be expected 3 out of 4 years in the two sections of the Blacklands

Northern Section		Southern Section	
Rainfall	Runoff	Rainfall	Runoff
Feet	Acre-feet per acre	Feet	Acre-feet per acre
4.5	0.49	4.4	0.52

7. Minimum amounts of rainfall (fig. 5) and runoff (fig. 4), and maximum evaporation (table 5), occurring during critical periods of 8, 12, 16, 20, 24, 28, and 32 months, must be considered in determining proper dimensions of a pond and size of drainage area required to maintain a dependable water supply, that is, a supply which will on the average not fail more frequently than once in about 25 years. These minimum amounts of runoff and rainfall are shown for both of the sections in figures 4 and 5. During those critical periods which in many cases control the design of farm ponds, the occurrence of minimum rainfall (fig. 5) will nearly always coincide with that of low runoff, and as the pond will not be full during these periods it is likely that all the rain that falls on the pond surface will be retained.

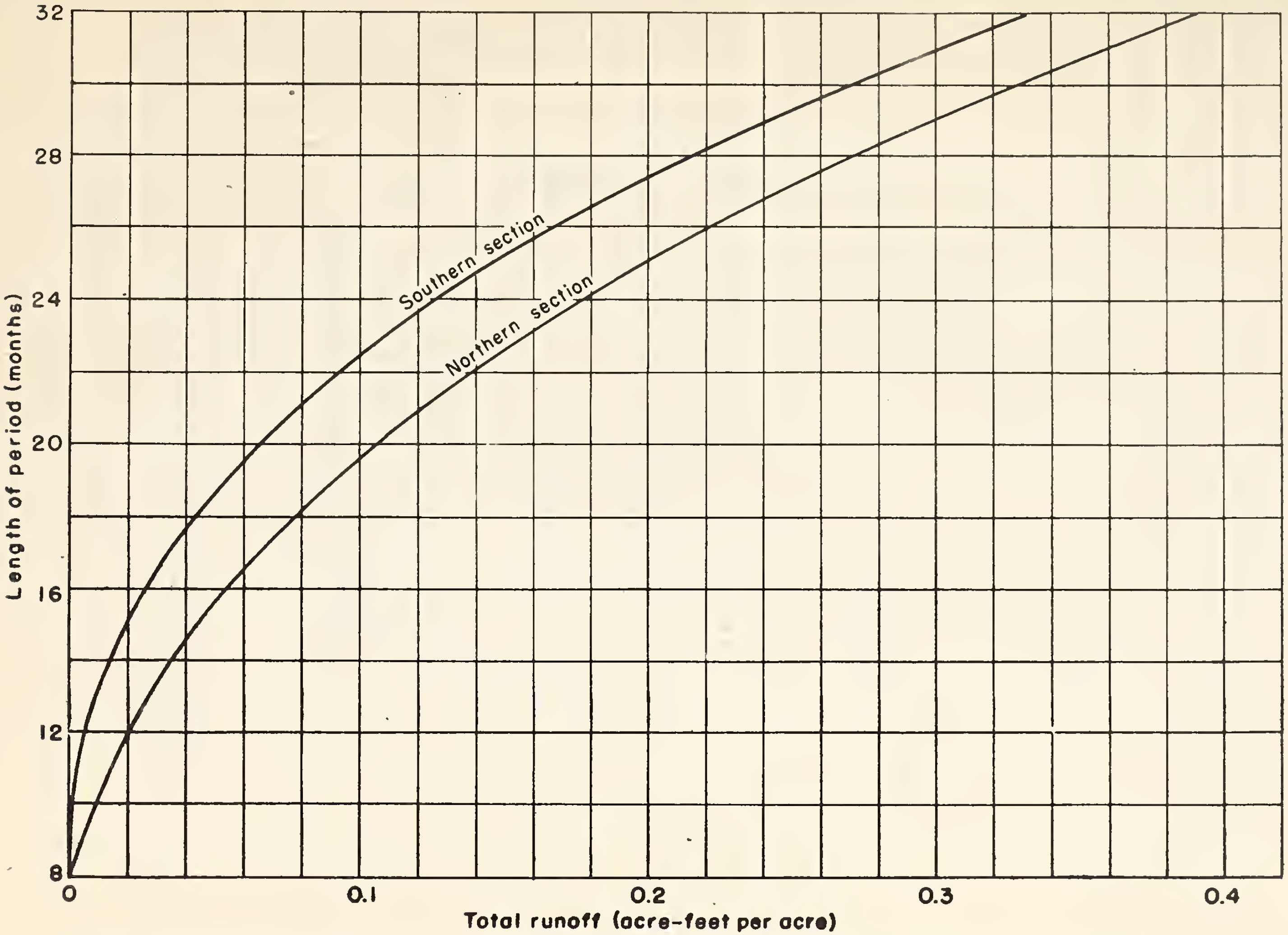

Figure 4.—Dependable amounts of runoff for cultivated land during critical dry periods of various durations. Cultivated land includes up to 40 percent in small grain, meadow, and pasture

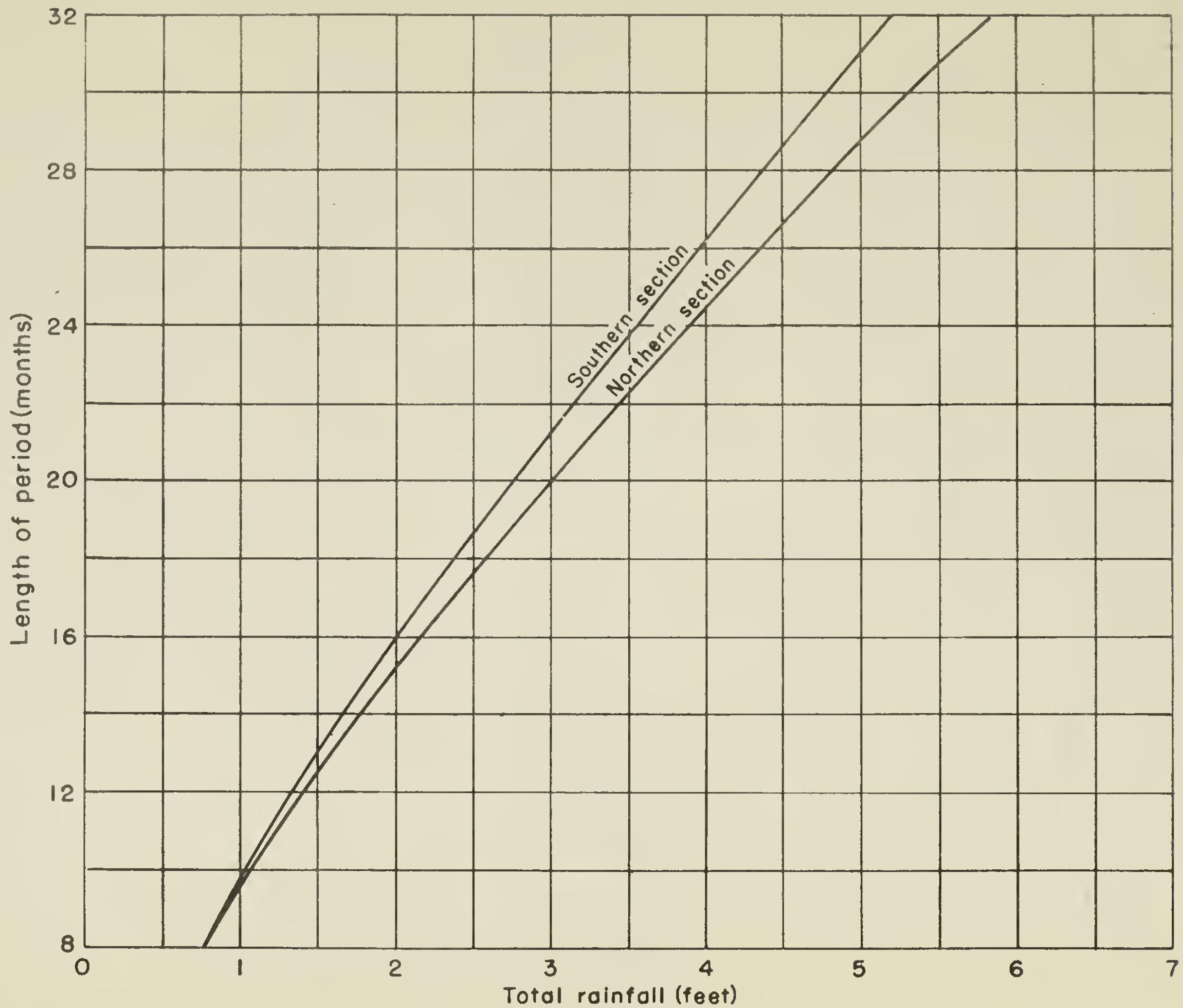

Figure 5.—Dependable amounts of rainfall during critical dry periods of various durations

Evaporation and seepage

Records at Austin, Temple, and Waco, adjusted for large free water surfaces, indicate an average annual evaporation from ponds, based on the highest evaporation from a Class A, U. S. Weather Bureau pan recorded in a 5-year period at Waco, was about 6.2 feet. The seasonal distribution of the average and maximum evaporation and greatest totals for various critical periods are shown in table 5.

Table 5.-- Seasonal distribution of evaporation from ponds, and values for various critical periods.

Period	Average	Maximum
	Feet	Feet
March - June	1.5	2.3
July - October	2.0	2.9
November - February	0.7	1.0
8-month total	3.5	5.2
12-month total	4.2	6.2
16-month total	6.2	9.1
20-month total	7.7	11.4
24-month total	8.4	12.4
28-month total	10.4	15.3
32-month total	11.9	17.6

No records have been obtained which would enable quantitative estimates of seepage losses. However, the nature of the soil and of the underlying marl or chalk in the Blacklands is such that seepage losses may be considered negligible, especially if the pond area is not too large and is not allowed to remain dry over long periods of time, and if areas underlain with shattered chalk or marl are avoided.

Erosion and silting of reservoirs

Erosion data from the Blacklands Experimental Watershed show that the type of land use and the degree of land slope of unterraced cultivated fields have a material effect on the amount of soil eroded (table 6). Data from the Blackland Experiment Station at Temple indicate that the erosional losses for cultivated terraces about 800 feet long on 3 to 5 percent slopes with variable grades and 4-foot vertical spacing, approximate those for cultivated unterraced fields on 2 percent slopes.

Table 6.-- Average annual amount of eroded material removed by runoff water from land with different slope and cover

Land Cover	Erosion from drainage areas with prevailing land slope of--							
	1 percent		2 percent		3 percent		5 percent	
	Tons per acre	Cubic feet per acre[2]	Tons per acre	Cubic feet per acre[2]	Tons per acre	Cubic feet per acre[2]	Tons per acre	Cubic feet per acre[2]
Unterraced: Mixed cover[1]	0.7	20	2.1	60	5.6	150	14	400
Clean cultivated	1.1	30	3.0	80	7.5	200	21	600
Meadow	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Terraced: Cultivated	-	-	-	-	3.0	80	3.0	80

[1] General land use distribution for the Blacklands: 60 percent clean cultivated, 20 percent in oats, and 20 percent in pasture-meadow.

[2] The value of 70 lbs. per cubic foot was used in converting tons per acre into cubic feet per acre.

Sedimentation survey data of reservoirs in various parts of the country indicate that for reservoirs with storage capacities ranging from 0.2 to 0.5 acre-feet per acre of drainage area, about 90 percent of the material is retained. In the Blacklands about 80 percent of the material retained is deposited in the reservoirs proper and 20 percent at the edge in the form of a delta. With the above values, the rates of silting per annum to be expected in reservoirs with storage capacities ranging from 0.2 to 0.5 acre-feet per acre of drainage area would be of the order shown in table 7.

Table 7.-- Estimated annual average amounts of silting in reservoirs with storage capacities ranging from 0.2 to 0.5 acre-foot per acre of drainage area

Size of drainage area[1]	Storage capacity of pond	Deposition in reservoirs on drainage areas with prevailing land slope of --									
		1 percent		2 percent		3 percent			5 percent		
		Clean cultivated	Mixed	Clean cultivated	Mixed	Terraced cultivated	Clean cultivated	Mixed	Terraced cultivated	Clean cultivated	Mixed
Acres	Acre-feet	Acre feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet	Acre-feet
2	0.4-1.0	0.0010	0.0007	0.0027	0.0020	0.0027	0.007	0.005	0.0027	0.020	0.014
4	.8-2.0	.0020	.0013	.0053	.0040	.0053	.013	.010	.0053	.040	.026
6	1.2-3.0	.0030	.0020	.0080	.0060	.0080	.020	.015	.0080	.060	.040
10	2.0-5.0	.0050	.0033	.0133	.0100	.0133	.033	.025	.0133	.100	.066

[1] Silting of reservoirs on drainage areas up to 300 acres in size can be assumed to be proportional to the size of the drainage area. Thus, the silting of a reservoir on a 75-acre drainage area in mixed crops having a 3 percent land slope is 75/10x0.025= 0.19 acre-foot.

It is to be noted that the values in table 7 for land slope of 3 percent or less are very small. If a meadow filter strip is used, very little if any eroded material would reach the reservoir. The above data on reservoir silting is presented to show the effect of steep slopes and land use, to emphasize the need of protective meadow strips, and to point out the inadvisability of establishing farm ponds on clean cultivated drainage areas with slopes in excess of 3 percent.

Relation between hydrologic factors and dimensions of ponds for dependable water supply

For small, relatively shallow stock ponds, the relationship for a definite period between the various hydrologic factors and the dimensions of the pond can be expressed as follows:

$$\frac{RA}{a} + P - \left(E + \frac{u}{a} + S\right) = d + \frac{W}{a} \text{ - - - - - - - - - - - - - (1)}$$

Where R = total runoff in acre-feet per acre.

A = the size of the drainage area in acres.

a = surface area of the pond in acres which, for excavated ponds, is nearly constant for the entire depth.

P = precipitation in feet falling on the pond which balances some of the evaporation and seepage irrespective of whether or not it produces surface runoff from the drainage area.

E = evaporation from the pond in feet.

u = amount of water in acre-feet used by livestock or otherwise.

S = seepage in feet.

d = increase (+) or decrease (-) in depth of water in the pond in feet; also total depth of usable water in the pond in feet.

W = amount of water in acre-feet in excess of the capacity of the pond which is wasted over the spillway.

It can be seen from equation (1) and the nature of the factors involved, that:

1. For a given site, seepage will in general be proportional to both the depth of water and the surface area of the pond. However, as already stated, seepage can be neglected in the Blacklands if areas underlain by shattered chalk or marl are avoided.

2. For a given surface area of pond, (a) greater depths will provide more storage and less water will be wasted over the spillway; (b) when runoff and rainfall are less than evaporation losses plus water utilized during a given period there will be no waste, and the storage in a deeper pond will supply the deficiency for longer periods than smaller storage in a shallower pond.

3. Evaporation depth expressed in feet is independent of the surface area and depth of pond in case of small, relatively shallow ponds.

4. The increase in depth of water due to a given amount of precipitation falling on the pond is independent of the surface area or depth of the pond.

5. The increase in depth of water due to a given amount of runoff varies inversely with the surface area of the pond; the greater the surface area, the smaller the increase in depth produced by a given amount of runoff.

6. The decrease in depth due to a given use will vary inversely with the surface area of the pond.

It follows from the above that:

(a) To prevent excessive waste over the spillways of farm ponds detrimental to the vegetative lining commonly used, the size of the watershed area should not exceed that required to fill the pond within a reasonable time of completion and to produce a sufficient supply during critical dry periods.

(b) The depth of usable water in a farm pond can in no case be smaller than the difference between the total demand and the total supply during the critical period expressed in the following equation:

$$d \geqq (E + \frac{u}{a}) - (\frac{RA}{a} + P) \text{ - - - - - - - - - - - - - - - (2)}$$

(c) For critical periods when no runoff can be expected, the minimum allowable surface area of a pond with a given depth is expressed as follows:

$$a \geqq \frac{u}{P + d - E} \text{ - - - - - - - - - - - - - - - - (3)}$$

(d) The minimum drainage areas required are determined by the following conditions: (1) The net volume of water in acre-feet, $[(RA + Pa) - (Ea + u)]$, available for filling the pond within a reasonable time (12 to 20 months) after its completion (this condition governs when the capacity of the pond is large, in which case the minimum drainage area required for a deep pond with a given surface area will be greater than that required for a shallower pond with the same surface area); and (2), the depth of water in the pond available to supply the required net amount of usable water during critical dry periods. The second condition governs when the capacity of the pond is small, in which case the minimum drainage area required for a dependable supply in a pond with a given surface area will vary inversely with the depth of the pond.

Other deductions which follow from the relationship expressed in equation (1) can be made from the curves (figs. 6 and 7) discussed under "Application of hydrologic data in the design of farm ponds."

Application of hydrologic data in the design of farm ponds

From the values of minimum rainfall and runoff amounts for various critical dry periods (figs. 4 and 5) and of maximum evaporation (table 4), a set of curves (figs. 6 and 7), showing minimum drainage areas, exclusive of the surface area of the pond, required to fill ponds of various dimensions and to maintain a dependable water supply of 0.2 and 0.5 acre-foot per year after the ponds are once filled, were developed for both sections of the Blacklands. These curves apply to ponds with surface areas up to 2 acres and with depths ranging from 6 to 10 feet. The curves and the procedure outlined below are based on the assumption that the surface area of the pond is reasonably constant throughout its depth. The banks of the ponds therefore must be as steep as possible and the water-surface areas large enough so that the percentage differences between water-surface areas when the pond is full, half full, and nearly empty are reasonably small. The use of these curves in selecting the proper dimensions of farm ponds when the drainage area is fixed, or in determining the minimum area required when either the depth or surface area is fixed, is demonstrated in problem A below. The procedure to be followed in the design of ponds

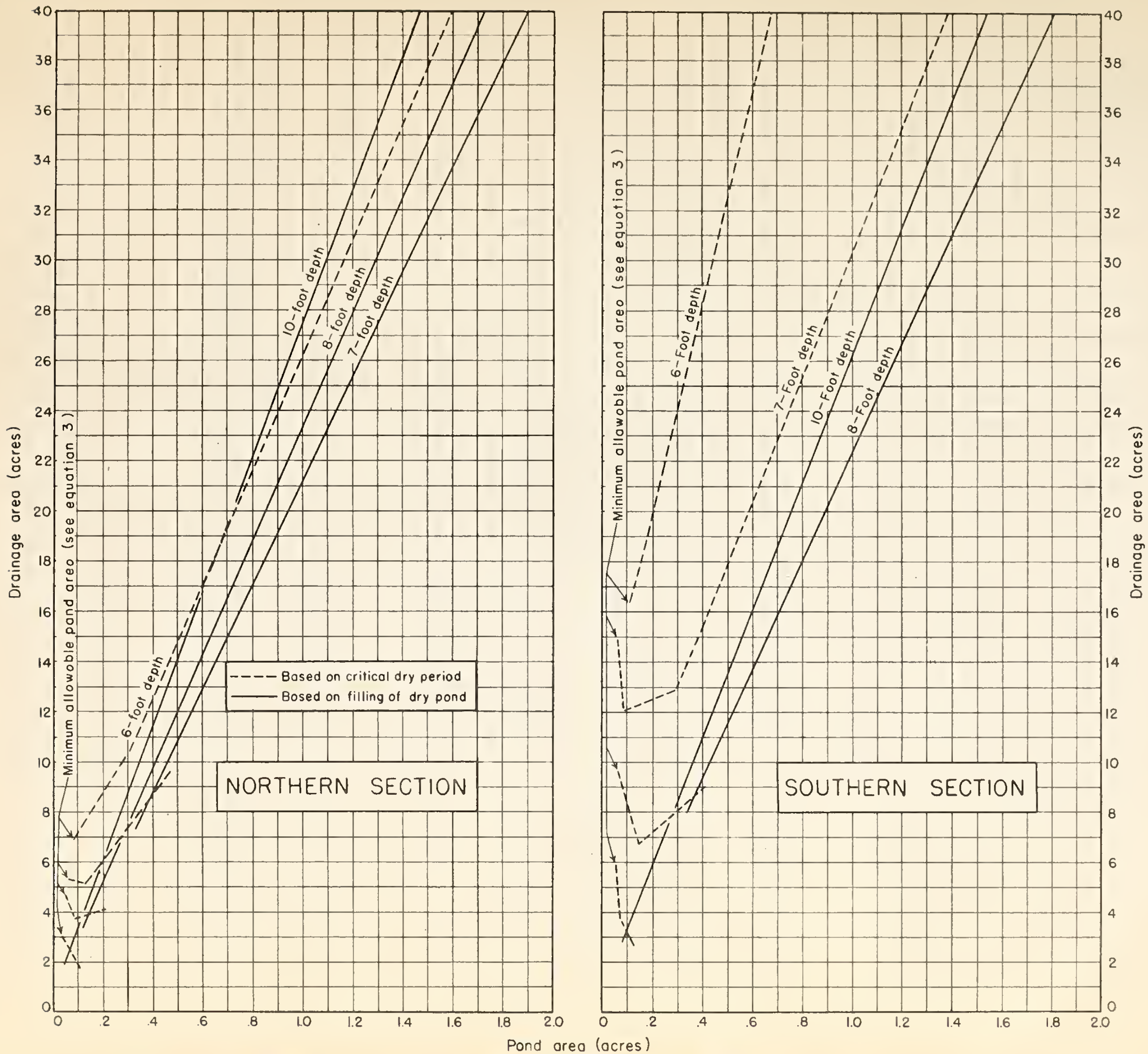

Figure 6.- Minimum drainage area required for a dependable water supply of 0.2 acre-foot per year

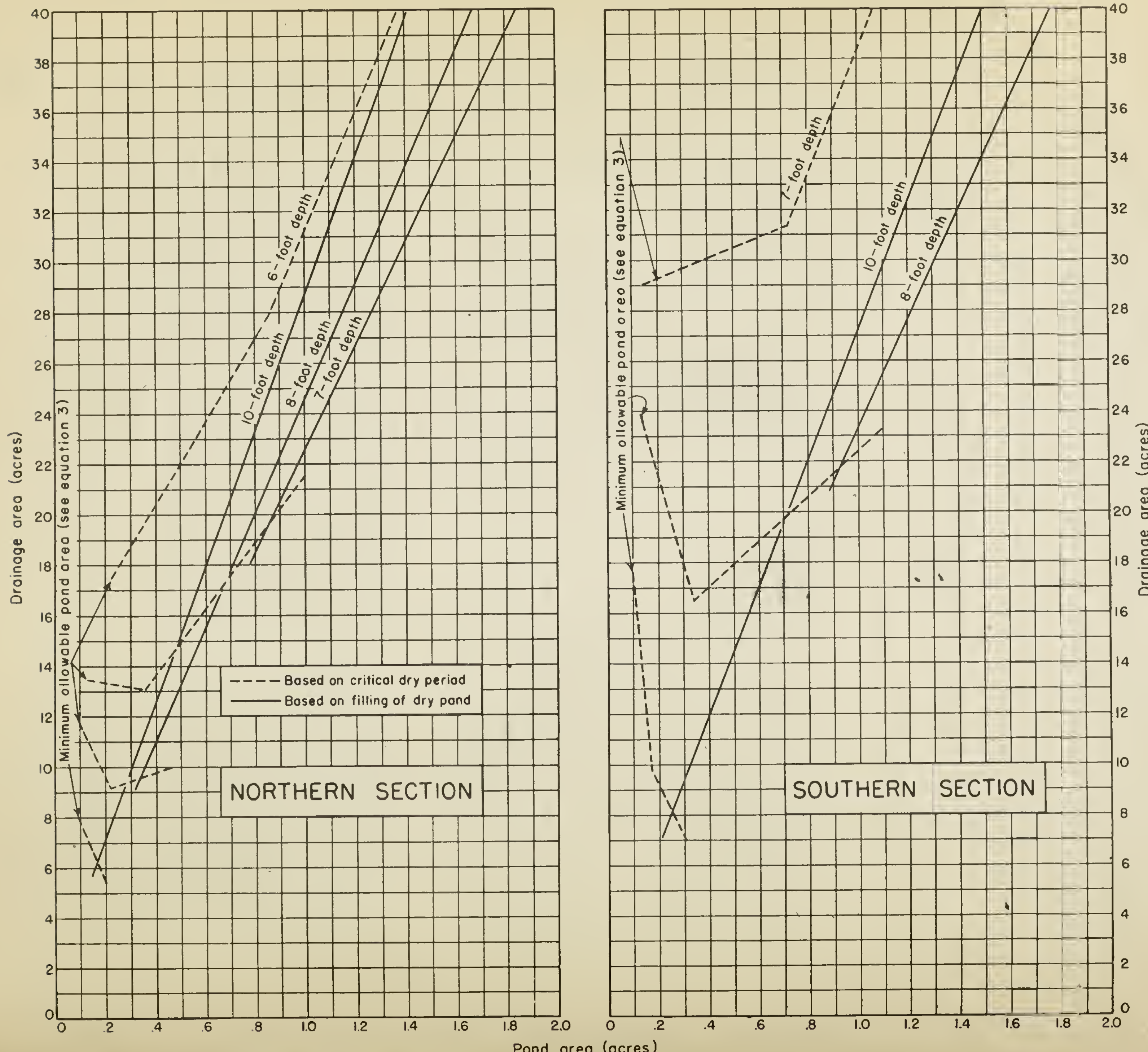

Figure 7.—Minimum drainage area required for a dependable water supply of 0.5 acre-foot per year

for required annual amounts other than 0.2 and 0.5 acre-foot is outlined in problem B. As the water in the bottom of the pond cannot conveniently be used, at least an extra 6 inches of depth must always be provided.

Pond designs and drainage area requirements determined according to the method described in this report are dependable and need no "factor of safety" applied, as it was assumed that the minimum rainfall, minimum runoff, and maximum evaporation are concurrent. These phenomena are not always coincident as revealed by the fact that the rainfall for a 20-month period of minimum runoff is often greater than a 20-month rainfall of recurrence equivalent to that of the 20-month minimum runoff period. This also applies to periods other than 20 months. Furthermore, the value of greatest total evaporation for a certain period is used although it is possible to have a smaller total evaporation. For example, the greatest total evaporation (maximum in table 5) for 20 months is 11.4 feet beginning in March, whereas the maximum evaporation for a 20-month period beginning in November totals 9.5 feet. The value of 11.4 and similar values of greatest total evaporation for other durations were used in developing the design curves.

IMPORTANT NOTE

The portions of the curves (figs 6 and 7) governed by amounts of rainfall and runoff required to fill the ponds are based on rainfall and runoff for 20 months which can be expected 3 out of 4 years. The portions of the curves governed by amounts required during critical dry periods are based on the assumption, which is generally valid, that the ponds are full at the beginning of critical dry periods. It therefore must be understood that some time (12 to 20 months) may elapse before ponds with large capacities are filled and before small ponds completed during or at the beginning of a critical dry period begin to function in accordance with the above mentioned assumption.

The concept of the recurrence interval must also be clearly understood and its meaning carefully explained when technical assistance in the planning of farm ponds is rendered if misunderstandings and possible disappointments are to be avoided. A "dependable water supply" for a farm pond is defined in this report (see par. 4, p. 8) as a supply which will, on the average, not fail more frequently than once in about 25 years. This does not mean that the possible failure of the supply will occur at the end of a 25-year period following the completion of the pond. A severe prolonged dry period causing failure of the water supply may occur at any time; however, over a long period the number of such failures on the average will not exceed one in 25 years.

Problem A - Use of curves in figures 6 and 7.

Case 1. Selection of proper dimensions of pond --

Given:

(a) Location - Garland, Tex. (northern section);

(b) Required supply - 0.2 acre-foot per year for watering horses, cows, and other animals on a 100-acre farm;

(c) Drainage area above desired site is 5 acres of land with 3 percent slope;

(d) Funds and equipment available for total excavation not to exceed 3,000 cubic yards;

(e) Site underlain by consolidated Austin chalk through which seepage is negligible.

Solution

(a) To insure full utilization of the dependable supply, the actual total depth of the pond must be at least 6 inches greater than the "usable depth."

(b) Fig. 6 for the Northern Section shows that with a drainage area of 5 acres a dependable supply can be obtained with --

(1) A pond with an 8-ft. usable depth and a range in surface area of 0.05 to 0.19 acre,

(2) A pond with a 10-ft. usable depth and a range in a surface area of 0.03 to 0.16 acre.

The range in dimensions and in excavation is as follows:

Usable depth	Range in surface area	Range in pond capacity	Total depth required	Range in excavation
Feet	Acres	Acre-feet	Feet	Cubic yards
8	0.05-0.19	0.04-1.52	8.5	690-2,600
10	0.03-0.16	0.30-1.60	10.5	506-2,700

A pond 10 feet deep with a surface area of 0.03 acre requires the least excavation, occupies the least space, and has the greatest waste over the spillway.

Within the range in dimensions specified above, the most desirable combination of depth and surface area will be determined by existing conditions. For instance, if propagation of fish is contemplated, the additional cost of a pond with a larger surface area may be fully justified. On the other hand, if fish propagation is not contemplated, and the spillway happens to be very wide and on a flat slope with an adequate lining or is entirely on consolidated rock, then the combination of pond depth and surface area resulting in the least excavation may be used.

(c) A protective meadow strip sufficient to prevent silting of the pond must be provided.

(d) To insure the supply, at least 60 percent of the drainage area must be in crops, intertilled. Of the remaining 40 percent, not more than half can be in meadow or lightly grazed pasture.

(e) Except for a small portion where cattle enter the pond, the slopes of the banks should equal the angle of repose of the soil.

Case 2. Determine minimum drainage area required for a dependable supply:

Given:

(a) Location - Garland, Tex. (northern section)

(b) Required supply - 0.5 acre-foot of water annually for a small herd of dairy cattle;

(c) Funds and equipment available for total excavation not to exceed 4,000 cubic yards;

(d) Surface area of pond not to exceed 0.5 acre;

(e) Depth of pond not to exceed 10 feet;

(f) Site underlain with consolidated marl, seepage negligible.

Solution

(a) Figure 7 for northern section shows a minimum drainage area of 9.2 acres for a pond with a nominal depth of 8 feet and surface area of 0.23 acre. Total excavation $= (8 + 0.5)\ 0.23 \times \frac{43560}{27} = 3{,}170$ cubic yards.

(b) Items (c), (d), and (e) under "Solution, Case 1" apply.

Problem B - Design of farm pond for conditions not covered in figures 6 and 7.

Case 1. Determine the minimum drainage area for dependable supply.

Given

(a) Location - Riesel, Tex. (northern section).

(b) Required supply - 0.35 acre-foot of water annually for a small herd of cattle; one-quarter supply in period March-June; one-half, July to October, and one-quarter, November to February.

(c) Surface area of pond, 0.2 acre.

(d) Funds and equipment available to excavate pond to a depth of 7-1/2 feet.

(e) Seepage losses negligible.

Solution

(a) Minimum allowable surface area of pond during critical periods of zero runoff.

From figure 4, period of zero runoff for central section = 8 months. Apply equation 3 on page 15

$$a \geqq \frac{u}{P + d - E}$$

a = surface area of pond = 0.2 acre

u = required supply for 8 months = 0.26 acre-foot

d = pond depth, usuable water = 7.0 feet

P = precipitation for 8 months (from fig. 5) = 0.8-foot

E = maximum evaporation for 8 months (from table 5) = 5.2 feet

$$0.2 \geqslant \frac{0.26}{0.8 + 7 - 5.2}$$

$0.2 \geqslant 0.10$, therefore pond area of 0.2 acre is satisfactory

(b) Minimum drainage area required to fill pond:

$$A = (d - P + E + \frac{u}{a}) \frac{a}{R}$$

A = minimum drainage area (acres)

d = usable depth of pond = 7 feet

a = surface area of pond = 0.2 acre

u = required supply for 20 months = 0.61 acre-foot

From tables 4 and 5.

E = evaporation for 20 months = 7.7 feet

P = precipitation for 20 months = 4.5 feet

R = runoff for 20 months = 0.49 $\frac{\text{acre-foot}}{\text{acre}}$

$$A = (7 - 4.5 + 6.4 + \frac{0.61}{0.2}) \frac{0.2}{0.49}$$

$$= 5.4 \text{ acres}$$

(c) Minimum drainage area required to maintain dependable supply after pond was filled.

Equation for pond 7 feet deep and with surface area of 0.2-acre

$$A = (E + \frac{u}{a} - P - d) \frac{a}{R} = (E + 5u - P - 7) \frac{0.2}{R}$$

Consider critical periods of 12, 16, 20, and 24 months. Maximum values of u based on 0.35-acre-foot per year, maximum values of E obtained from table 4, and values of R and P obtained from figüres 4 and 5 are as follows:

Period months	u	E	P	R	$(E+5u-P-7)\frac{0.2}{R} = A$
12	0.35	6.2	1.4	0.020	$(6.2 + 1.75 - 1.4 - 7)\frac{0.2}{0.02} = -4.5 = A$
16	0.44	9.1	2.2	.054	$(9.1 + 2.20 - 2.2 - 7)\frac{.2}{0.054} = +8.1 = A$
20	0.61	11.4	3.0	.105	$(11.4 + 3.05 - 3.0 - 7)\frac{.2}{0.105} = +8.5 = A$
24	0.70	12.4	3.9	.178	$(12.4 + 3.50 - 3.9 - 7)\frac{.2}{0.178} = +5.6 = A$

Since the 20-months period requires the greatest drainage area, trials with longer critical periods are not necessary. The minimum drainage area required to maintain a dependable supply is, therefore, 8.5 acres.

(d) Conclusions:

(1) Minimum drainage area required to maintain a dependable supply is 8.5 acres which is larger than that required to fill the pond. Use 8.5 acres.

(2) Total depth of pond = 7.5 feet.

(3) Usable storage capacity = 1.4 acre-feet.

(4) Total excavation $\frac{7.5 \times 0.2 \times 43560}{27} = 2{,}420$ cubic yards.

(5) Paragraphs (c), (d), and (e) of Problem A, Case 1 apply.

Spillways for farm ponds

Spillways for farm ponds or other impounding reservoirs shall be designed and constructed according to the standard Soil Conservation Service engineering procedure for the Blacklands, or that specified on pages 56-65 of Farmers' Bulletin No. 1859[1]. It is recommended that spillways for farm ponds be designed to carry a peak flow of 10-year recurrence interval (tables 2 and 3). As most ponds will not have enough storage above spillway crest to cause a material reduction in the peak rate, the peak rates given in tables 2 and 3 are to be used without modification. Inasmuch as (1) a freeboard of about 1 foot is usually provided, (2) there will be some reduction in peak rate due to pond storage, and (3) the peak flow will probably be of short duration, it is likely that a 25- or 50-year flood peak will be passed without causing material damage.

[1] "Stock Water Developments," U. S. Department of Agriculture.